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Forest succession in the southern limits of Early Wisconsin glaciation as indicated by a pollen spectrum from Bacon's swamp, Marion county, Indiana

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The *Butler University Botanical Studies* journal was published by the Botany Department of Butler University, Indianapolis, Indiana, from 1929 to 1964. The scientific journal featured original papers primarily on plant ecology, taxonomy, and microbiology. The papers contain valuable historical studies, especially floristic surveys that document Indiana's vegetation in past decades. Authors were Butler faculty, current and former master's degree students and undergraduates, and other Indiana botanists. The journal was started by Stanley Cain, noted conservation biologist, and edited through most of its years of production by Ray C. Friesner, Butler's first botanist and founder of the department in 1919. The journal was distributed to learned societies and libraries through exchange.

During the years of the journal's publication, the Butler University Botany Department had an active program of research and student training. 201 bachelor's degrees and 75 master's degrees in Botany were conferred during this period. Thirty-five of these graduates went on to earn doctorates at other institutions.

The Botany Department attracted many notable faculty members and students. Distinguished faculty, in addition to Cain and Friesner , included John E. Potzger, a forest ecologist and palynologist, Willard Nelson Clute, co-founder of the American Fern Society, Marion T. Hall, former director of the Morton Arboretum, C. Mervin Palmer, Rex Webster, and John Pelton. Some of the former undergraduate and master's students who made active contributions to the fields of botany and ecology include Dwight. W. Billings, Fay Kenoyer Daily, William A. Daily, Rexford Daudenmire, Francis Hueber, Frank McCormick, Scott McCoy, Robert Petty, Potzger, Helene Starcs, and Theodore Sperry. Cain, Daubenmire, Potzger, and Billings served as Presidents of the Ecological Society of America.

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FOREST SUCCESSION OF THE SOUTHERN LIMITS OF EARLY WISCONSIN GLACIATION AS INDICATED BY A POLLEN SPECTRUM FROM BACON'S SWAMP, MARION COUNTY, INDIANA[1]

By JAMES H. OTTO

In the past few years, the Botany Department of Butler University has conducted an extensive study of Indiana peat bogs. Such a study will throw much light upon the history of Indiana vegetation. This paper is a portion of the greater survey and describes results from the southernmost bog studied.

The name "Bacon's Swamp" has its origin by common usage of natives of the region. The area is a typical glacial peat bog of the kettle hole type, and is in no sense a swamp. According to Potzger (15), "A swamp is a feature of the topography where the water table is above the surface and the soil is inorganic or of a humus nature." A bog, on the other hand, is "a feature of the topography where the water table is at or near the surface and the soil is of organic origin (peat) formed in situ." This location is, therefore, a true bog, but will be referred to in this paper as Bacon's Swamp.

Bacon's Swamp, located about the center of Marion county, Indiana, and nearly within the city limits of Indianapolis, presents a very interesting paleological problem due to its unique location. On the southern limits of the bog area of Indiana, it is a true Early Wisconsin peat bog, covering an area of approximately 30 acres and filled in with 32 feet of peat and marl. The Northern Moraine or Lake Region described by Malott (14) contains many bogs, but a bog in Marion county, approximately one hundred miles south, is indeed a rare occurrence. Therefore, the records from this bog are of special significance.

Cooper (6) describes the advance of the boreal forest "on the heels of the retreating glacier" on Muir Inlet, Glacial Bay, Alaska. His investigation shows the nature of succession at the present northern limits of the forest area. Bacon's Swamp, being near the southern glacial boundary of the Wisconsin ice sheet, is located uniquely to show succession when this great boreal forest had its northern limits in Indiana. The analysis of fossil pollen from Bacon's Swamp has also shown the invasion of the boreal forests by more southern species, which today in

[1]This paper is a portion of a thesis in partial fulfillment of the requirements for the degree of Master of Arts in Butler University.

Indiana have reduced the older forests to boreal relicts such as those described by Friesner and Potzger (9) and (10).

GEOLOGY OF MARION COUNTY

Marion county, located near the center of the state of Indiana, lay in the path of several great continental glaciers of past ages. Little evidence of the earlier glaciers is left, due to the obliteration of the drift by the more recent Illinoian and Wisconsin ice sheets. This series of glaciers has greatly influenced the topography of the county. Malott (14) believes that the Illinoian ice sheet advanced through Marion county over a dissected area much like the driftless region of Central Southern Indiana, often referred to as the Knobs area. It covered the bed rock in Marion county with a drift in some places several hundred feet deep. The Illinoian glacial boundary is well defined in Indiana, showing a division of the sheet at the southern boundary of Johnson county. One arm continued southwest and one southeast, toward Cincinnati. Marion county, therefore, is located near the Illinoian glacial boundary.

A later glacier, the Early Wisconsin ice sheet, passed through Indiana and further altered the topography. It buried the Illinoian glacial formatious with layers of drift as much as 50 feet deep in many places. Malott (14) shows the southern boundary of the Early Wisconsin glacier to be lobed in outline and running across Indiana in a general southeastern direction from Parke county. The southwest corner of Marion county is very near the boundary, as shown by several high moraines in the region of Glenns Valley and Mooresville, Indiana.

A second or Late Wisconsin ice sheet is believed to have passed over northern Indiana as far south as Logansport, in Cass county, approximately 60 miles north of Bacon's Swamp. Malott (14) refers to it as a Wisconsin substage. This would account for the abundance of lakes and bogs in that part of the state, commonly referred to as the Lakes Region. Such an explanation also dates the bogs south of the substage boundary as much older than the northern Indiana bogs. Bacon's Swamp is, therefore, of Early Wisconsin glacial origin.

BIOTIC INFLUENCES

Located in a large and rapidly expanding city, civilization has done much to alter Bacon's Swamp in recent years. The normal succession of vegetation in the bog has been hastened greatly by these biotic influences. It is interesting, however, that most of these changes have occurred recently. The author, having lived in the vicinity of the bog for the past 15 years, has observed many of these changes. Douglas (7), in 1905, described the area as a typical Sphagnum bog, bearing Sphagnum as richly as a Michigan or Wisconsin peat bog, or even better. Cain (4), in describing the vegetation of Bacon's Swamp, refers to small areas of living Sphagnum as late as 1927-1928. At the present, only very small traces of Sphagnum are left, and the bog has advanced to the Calamagrostis-meadow stage. The disappearance of Sphagnum is due to the annual fires which sweep the sedge-meadow.

Ten years ago, Bacon's Swamp was widely known as an excellent area for study of aquatic flora and fauna. The basin contained water throughout the year and flooded to a shallow lake stage in the spring and fall. Many species of water birds stopped at the lake during the spring migratory season, and some remained throughout the summer. The author recalls seeing broods of ducklings and the young of herons, bitterns, and other waterfowl. The bog also provided suitable habitat for many species of reptiles and amphibians, as well as aquatic mammals such as muskrats.

Comparing the conditions in the bog today with those of such a short time ago, it seems unbelievable that so many changes could have occurred. One of the early biotic influences was the attempt in 1914 to extend a street through the middle of the bog. A roadbed of gravel and dirt was laid above the peat mat, and the road was completed. However, the following year, the weight of the roadbed compressed the peat and the road disappeared. This produced an interesting rectangular pond in the center of the swamp. Cain (4) states that this pond would appear quite strange to one who did not know its origin. The road was abandoned from 1915 until about two years ago when the project was renewed. Several times in the past two years the road has been completed and would support the weight of trucks, only to sink again below the surface following further compression of the peat. The weight of the fill has forced the peat out on both sides of the road in large mounds several feet high. Another more successful attempt to construct a road has been made several hundred feet to the north across the north arm of the swamp.

Perhaps the greatest changes in the topographical and vegetational features of the swamp are the result of a lowering of the water table in the past 10-15 years. The exact reason for this drying out is somewhat questionable. In its present condition, the swamp dries out each summer with the exception of the pond formed by the sunken street and a small water hole in the southwest end. The water table, during that season, is one to two feet below the surface of the mat. Cain (4) suggests that the lowering of the water table is due to tilling of the surrounding land. A drain in the north end of the bog has also helped to lower the water table.

Still another factor influencing the present vegetation in the bog is the periodic autumn burning of the dried grasses and sedges. The author has observed annual fires occurring about the month of August for the past eight to ten years. Most of these blazes are probably of incendiary origin. The desiccated plants in the meadow at that season produce a roaring fire which destroys all vegetation in its path, and even burns several inches into the peat. Holes of such origin may be found in many places, particularly in the southwest corner where the Calamagrostis-meadow is best developed.

The swamp forest has been partially destroyed quite recently as a result of cutting and clearing. The trees were too small to be of commercial value, but were removed as a part of a project to reclaim the land. The forest in the north end especially has been damaged in this manner.

PRESENT VEGETATION

The influence of civilization which has so greatly altered conditions of the bog in recent years, has also produced some interesting features in the vegetation. The lowering of the water table occurred over such a relatively short period that several stages in the succession of the hydrosere exist in the swamp at the present time. Mingled with the plants now controlling, are species of a more hydrophytic nature which flourished a short time ago.

As in many other peat bogs, the vegetation of Bacon's Swamp occupies rather definite zones. The central area is now controlled by *Calamagrostis canadensis*. Mingled with the grasses in the wet meadow are *Dryopteris thelypteris pubescens, Juncus canadensis,* and *Hypericum virginicum*. In the southwest end, scattered islands of *Decodon verticillatus* remain from a time of more hydrophytic conditions. Cain (4) refers to these islands and accounts for their existence by the presence of somewhat deeper water in that end of the swamp. In 1927 the Decodon islands were quite prominent, but since that time have been invaded by the wet meadow. Other relics of more hydrophytic conditions are scattered clumps of yellow pond lilies (Nymphæa) growing in low places in the meadow. Typha is restricted somewhat to areas near the deepest part of the bog, where some water remains throughout the year except during very dry seasons.

Like many other Sphagnum bogs, Bacon's is surrounded by a moat. This area of open water is, in most places, 15 to 20 feet wide, and extends from the margin to a zone of Cephalanthus which borders on the Calamagrostis-meadow. At present, much of the Cephalanthus is dead, but the width of the zone indicates more favorable conditions a short time ago. Cain (4) found much of the Cephalanthus to be dying out in 1927, and remarked about the large amount of dead wood and the extensive root systems to support very few living branches.

Another interesting zone of vegetation is occupied by *Salix nigra*. Perhaps this area should be included in the swamp forest, but is restricted to the moat and to a few low places in the southwest portion of the wet meadow. The willow occupies a zone outside of Cephalanthus for the most part, but in some places mingles with it.

The swamp forest proper surrounds the bog. One of the most prominent species of this area is *Fraxinus profunda*, which in several places exists in nearly pure stands. One of these stands is located along the west shore of the north end of the bog. Other constituents of the swamp forest include *Acer rubrum*, *Ulmus fulva*, *Nyssa sylvatica*, *Quercus bicolor*, and *Quercus palustris*.

The upland forest around the bog is typical for central Indiana, composed of *Fagus grandifolia*, *Acer saccharum*, *Acer saccharinum*, *Quercus alba*, and *Quercus borealis maxima*. Associated with these in lower frequency classes are Fraxinus sp., Carya sp., *Liriodendron tulipifera*, *Prunus serotina*, and *Gleditsia triacanthos*. Cultural influences have almost entirely eliminated this climax forest.

METHODS

Four sets of peat samples were obtained over a period of several years. Under the direction of Dr. J. E. Potzger, classes in ecology made three borings; the fourth set was obtained during the winter of 1936. All of the borings were made in an approximately straight line across the southwest portion of the bog. Boring IV was made at a point about 250 feet from the east shore and about 100 feet south of the pond formed by the sinking of the roadbed of Fifty-sixth street into the bog. This was the deepest of the four borings. Boring I was made about 150 feet southwest of IV. The other two borings were made in a straight line with I and IV. Boring III was taken about 300 feet southwest of I and II, 150 feet from III. Boring II was made within 150 feet of the west edge of the bog.

The samples were taken with a special peat borer, consisting of a hollow chamber with a movable sleeve, permitting the cylinder to·be opened and closer below the surface by turning the handle. Material was collected at each foot level, beginning with one foot below the surface, and the portion to be used for examination was taken from the center of the core, thus reducing the possibilities of contamination. As an added precaution against contamination, the chamber was thoroughly washed between collection of samples. Each sample was placed into a small bottle and labeled. Upon returning to the laboratory, the bottles were sealed with paraffin to prevent drying out.

Separation of the peat and slide preparation followed, with a few modifications, the method suggested by Geisler (11). It was found that the preparation of slightly more peat than the amount suggested by Geisler increased the pollen content of the slides. Into a small beaker (25 cc) was placed a heaping scalpelful of peat. To this sample was added about 15 cc of 95 percent alcohol. The peat was then stirred gently with a camel's-hair brush until the floccules had mixed thoroughly with the alcohol. Four drops of 1 percent aqueous gentian violet stain were then added and the material stirred thoroughly for several minutes. The suspended peat was allowed to settle out after stirring. By means of a pipette, the upper surface of the precipitate was skimmed. Several drops of material were placed on a glass slide until the alcohol had nearly evaporated. While the peat was slightly moist, a drop of glycerin jelly was added and the material mixed thoroughly with the jelly by means of a clean camel's-hair brush. A cover slip was then added to the slide. It was found that the pollen grains darkened for several days after mounting, so all slides were allowed to stand for at least two days before examination. Few grains were broken, and the pollen was well separated from the peat.

Pollen determination was accomplished by comparison with modern pollen and the descriptions and illustrations of Wodehouse (23) and Sears (18). The pollen frequency was based on a count of 200 grains, except in the lower levels where few species were represented, and in some of the upper levels where pollen grains were scarce, in which cases, 100 grains were counted.

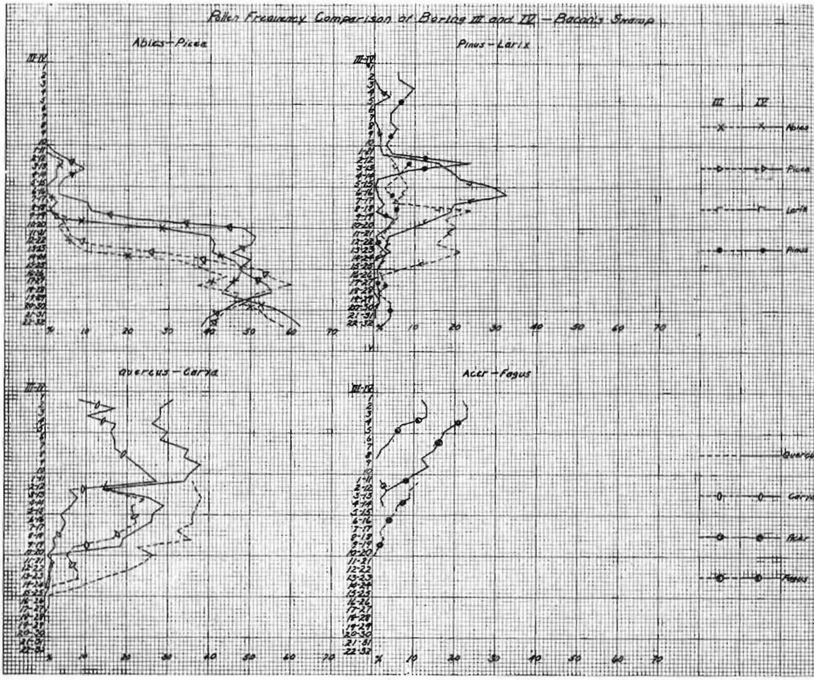
OBSERVATIONS

In all, four borings were made, but only two were selected for pollen analysis. Boring IV was chosen because of its depth, 32 samples having been obtained. Boring III, 22 feet deep, was used because of its greater distance from boring IV. The results of the pollen analysis of boring IV are presented in graph form in figure 1. The results from the two borings were very similar, both in the nature of the peat obtained and in pollen content, even though the two sets of samples were obtained in opposite ends of the southwest region of the bog. The upper seven levels in boring IV were composed of raw Sphagnum peat. Levels 8 through 15 were of a very coarse Carex peat. These samples were composed largely of the sedge remains through which were scattered bits of decayed Sphagnum. Below the Carex deposit, levels 16 through 23 were filled in with decayed Sphagnum peat. The bottom of this layer was so decomposed as to form a black jelly-like ooze. The lower nine levels, from 24 through 32, were marl. In the 32-foot level, the marl was mixed with coarse sand crystals, which would indicate the old lake bottom.

The pollen spectrum of boring IV reveals many changes in the forest cover of the Bacon's Swamp region since formation of the bog. Indicated in the spectrum is a forest succession from a boreal coniferous type to the broad-leaved mesophytic climax forest of today. Abies and Picea controlled during deposition of the lower levels. At the 32-foot level, 62 percent of the pollen represented was Abies. From this point, however, Abies declined and Picea pollen increased to higher frequencies to assume dominance over Abies. Control of the forest by these conifers continued until the 21-foot level. Here, Abies declined rapidly from 40 percent in the 21-foot level, to 2.5 percent in the 19-foot level, never showed dominance after this, and disappeared at the 11-foot level. Picea soon followed Abies, dropping from 48 percent in the 20-foot level, to 3 percent in the 16-foot level, and disappeared from the spectrum at the 10-foot level. Among the low frequency representatives of the lower 20 levels in the bog were Larix, Pinus, and the Salix-Populus group.

Interesting forest changes occurred while the levels 20 to 10 were deposited. With the rapid decline of Abies and Picea, other genera showed a marked increase. Larix, which had been represented in low frequency from the 31-foot level, increased rapidly at the 21-foot level. This increase continued to a peak of 32.5 percent in the 16-foot level. At that point, the percentages dropped steadily to 2 percent in the

FIGURE 2



11-foot level. Larix continued to the 2-foot level, but was represented only by low pollen frequency. The 20-foot level also marked the rapid increase of Quercus, Salix-Populus, and the Betula-Alnus-Corylus group. Quercus increased to 29 percent in the 14-foot level, and, after a slight drop in the 12-foot level, reached 35.5 percent in the 10-foot level. Salix-Populus remained about 15 percent to the 16-foot level, and then decreased. Betula-Alnus-Corylus also occupied a secondary position in the spectrum through the middle ten levels. Pinus, appearing first in the 28-foot level, continued in the lower frequencies to the 14-foot level, where a rapid increase was observed. The peak for Pinus, 23.5 percent, occurred in the 12-foot level. It declined to 10 percent above that point but persisted to the surface. Another broad-leaved invader of the coniferous forest was Carya. It appeared in the 23-foot level and evidenced little competition until the 12-foot level, where it suddenly increased from 6 percent to 27.5 percent.

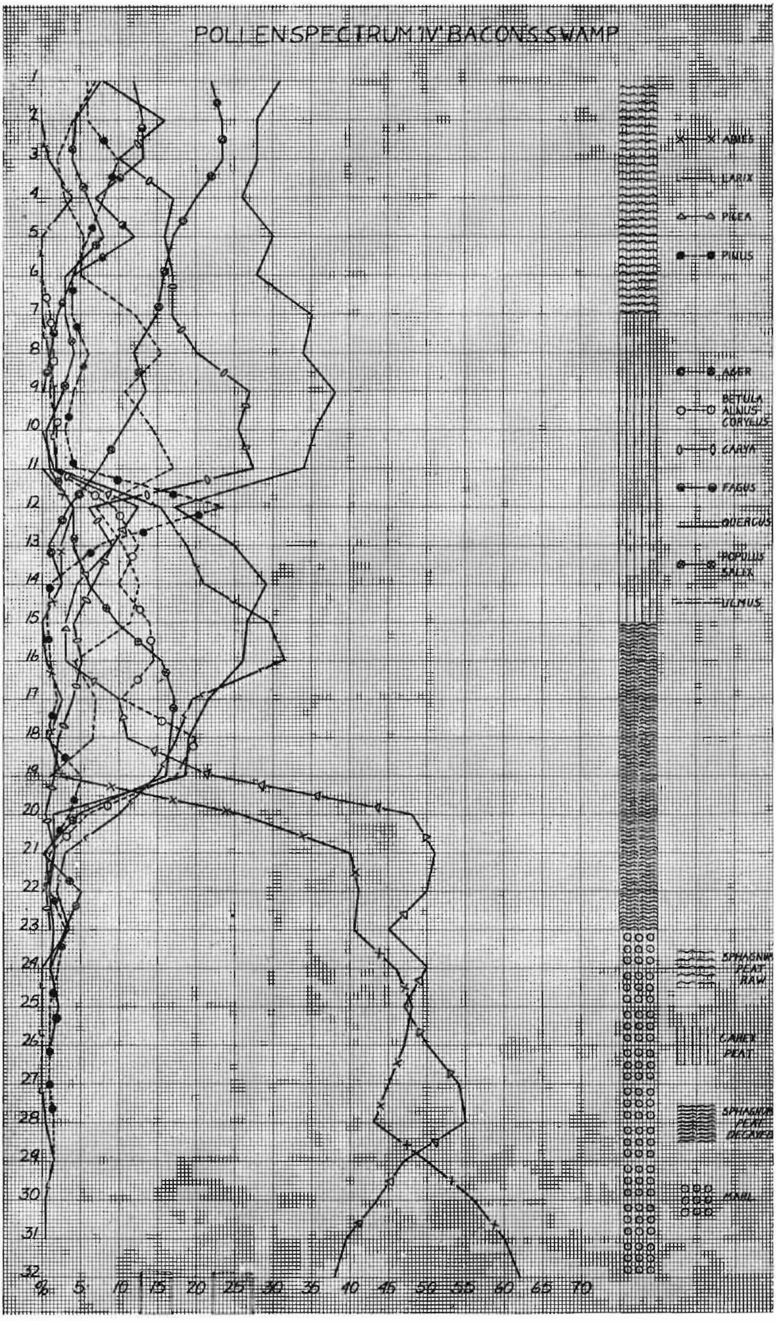
A third period of the forest succession, shown in the upper ten levels of boring IV, indicates a further advance toward a broad-leaved mesophytic climax forest, and a compensating reduction of genera prominent in the middle ten levels to secondary importance. Quercus shows no increase, but continues to be a dominant genus. Carya was also present in all of these levels but declined gradually from the 9-foot level to a frequency of 8 percent at the 1-foot level. Acer made its appearance at the 14-foot level and increased steadily to a 22 percent peak at the 1-foot level. This percentage is more significant if we consider that Acer produces but a small amount of pollen as compared with Carya and Quercus. Fagus came in at the 9-foot level and increased to 12 percent at the 1-foot level. The upper levels of the bog show Quercus, Acer, and Fagus as the dominant genera, while Carya, Salix-Populus, Ulmus, and Pinus decreased in frequency to secondary importance. As stated previously, Larix remained to the 2-foot level.

Juglans, Tilia, Fraxinus, and Thuja were represented in boring IV, but only as genera of secondary importance. These genera were omitted from the spectrum diagram, in figure 1, to simplify it. Tilia appeared in several levels above 20 feet, but showed no consistent increase or decrease. Juglans remained in the low frequency classes below the 10-foot level, and gradually increased to 10 percent in the 6-foot level, after which it decreased to about 5 percent and was thus represented to the surface. Fraxinus and Thuja were represented by only a few pollen grains in the upper levels.

In general, the pollen spectrum of boring IV may be divided into three periods. The lower 12 levels, from 32 to 20 feet, were controlled by Abies and Picea, with Pinus, Larix, and the Salix-Populus group present in the low-frequency classes. Levels 20 through 10 showed a rapid decrease of Abies and Picea and an increase in Quercus, Larix, Salix-Populus and the Betula group. In the 12-foot level, Pinus increased rapidly to a peak of 23.5 percent, but declined rapidly from that point. The spectrum again changed in the upper ten levels. Quercus maintained a high frequency to the surface, Carya decreased gradually, and Acer and Fagus increased to a position of codominance with Quercus.

Figure 2 shows a special comparative study of results obtained in boring II and boring IV. Four graphs were used to compare the genera which were most prominent in the pollen spectra of the two borings. In plotting the graphs, an attempt was made to arrange the 22 levels of boring III in time sequence with the 32 samples from boring IV. Assuming the bottom levels to be comparable, level 22 of boring III was

FIGURE 1


POLLEN SPECTRUM 'V' BACONS SWAMP
ABIES
LARIX
PICEA
PINUS
ACER
BETULA ALNUS CORYLUS
CARYA
FAGUS
QUERCUS
POPULUS SALIX
ULMUS
SPHAGNUM PEAT RAW
CAREX PEAT
SPHAGNUM PEAT DECAYED
MARL
%
5
10
15
20
25
30
35
40
45
50
55
60
65
70

made to correspond with level 32 of boring IV. The graphs shown in figure 2 reveal a striking similarity in the spectrum curves of the two borings.

This similarity between borings is well illustrated in the Abies-Picea graph. These conifers are shown to have dominated the spectrum during the same period in both borings. Both curves show an early dominance of the two conifers for about the same length of time, followed by a rapid decline in frequency. Similarity is shown, also, in the rapid disappearance of Abies and Picea from the spectrum of each boring. Another striking feature of the graph is the fact that while the same relationship exists between Abies and Picea in the borings, the curves seem to indicate a time error in the arrangement of foot-levels on the graph. An interval of about four feet separates the lines of the two spectra. If the frequency curves of boring III were plotted four foot-levels higher, the two borings would show a very close Abies-Picea correlation.

The other graphs also show a close relationship between the results of boring III and boring IV. The frequencies of Quercus and Carya show the same trends, although the lines of boring III again seem to be placed too low on the graph. The decrease of Carya is much more complete in the upper levels of boring IV than in III, suggesting that the 1-foot level of the latter is considerably older than the 1-foot level of boring IV. The rapid increase of Quercus beginning in the 20-foot level of boring IV is shown in the 15-foot level of III. Pinus was present through both spectra, but in the lower frequency classes. Larix showed the same rapid increase in the mid-sections of the borings, followed by sudden decrease, but again, about four or five foot-levels separate the curves representing the Larix frequency in the two borings.

Further evidence to indicate the absence in boring III of the pollens found in the upper levels of boring IV, is shown in the Acer-Fagus curves. Acer shows a frequency of 24 percent in the 1-foot level of boring IV and only 11 percent in the 1-foot level of III. Fagus, represented in eight levels in the deep boring and reaching 12 percent in the 1-foot level, was found in only two levels and in the low frequency classes in the 22-foot boring. As in the other three graphs in figure 2, raising the curves of boring III about four or five levels would result in a close correlation of the Acer-Fagus lines.

ACIDITY OF BORING IV

A study was made of the pH values of every level of boring IV. Readings were made with the Youden hydrogen-ion apparatus. Three readings were made for each of the 32 levels of the boring and their active acidities were averaged for an average pH value for each level. The results indicate a gradual decrease in acidity from upper levels of peat to the marl in the bottom of the basin. The peat at all levels was acid to slightly acid, while the marl was alkaline. It is interesting to note, however, that none of the peat showed a strong acidity. The 1-foot level, with a pH of 5.9, was the most acid in the bog. The other raw Sphagnum layers were decreasingly acid to the 8-foot level with a pH of 6.82. Carex and decayed Sphagnum peat, occupying the next layers from 8 to 23 feet, were found to be slightly acid, with an increase in acidity in levels 22 and 23. At the 24-foot level marl made its appearance and the acidity dropped to nearly neutral (6.9). Alkalinity increased to the bottom of the marl deposit. The highest alkalinity, pH 7.3, was found at the 30-foot level.

Acidity in the upper levels of the bog may be accounted for by the activity of Sphagnum and other mosses. The more rapid decay of the plant remains in the upper levels would also increase acidity. The most acid peat was at the 1-foot and surface levels, where the Sphagnum mosses have been active most recently. The acidity of these layers decreased to the Carex peat below. Newly formed peat which is near living Sphagnum is acid, but, as the mat becomes deeper, these levels become less acid. This decrease in acidity is evidently due to the entrance of water from the surrounding area, for the glacial till contains considerable limestone and shell debris from which the calcium carbonate may go into solution. The bog basin receives much water in wet seasons, thus permitting the limy material to seep down into the lower levels of the bog. Another cause for the decrease in acidity is the effect of fires which burn over the surface of the bog periodically. The alkaline ashes are washed into the peat and gradually seep into the lower layers, thus decreasing the acidity of the deposits.

The results of the pH study in Bacon's Swamp agree with those of other Indiana bogs as found by Potzger (16) in 11 Indiana bogs, including Bacon's. He found all of the bogs to be acid near the top, only slightly acid about the middle, and alkaline in the lower levels.

DISCUSSION

Discussion of such phases of the investigation as the validity of fossil pollen analysis as an indication of forest succession has been omitted because of adequate treatment of the subject by other investigators. G. Erdtman (8), Barkley (1), and otbers, have shown that reliable data may be obtained by the determination of the pollen content of peat. Correlation of results obtained from pollen analyses of numerous bogs in the Central States and Canada further testify to the validity of this branch of ecological research. Likewise, a discussion of various methods for separation of pollen from peat has been omitted. The method devised by Geisler (11) and used by Barnett (2), Prettyman (17), and Smith (21), yielded satisfactory results in the present study. The pollen spectrum obtained from borings in Bacon's Swamp agrees with the results obtained by Barnett (2) in Emporia bog, Madison county, and Prettyman (17) in Fox Prairie bog, Hamilton county, Indiana. The correlation found between these bogs is of special interest because of similarity in geological history. The three bogs are located below tbe southern boundary of the Late Wisconsin glacial substage and are therefore older than the bogs of northern Indiana. Any extensive migration of the forests recorded by the presence of preserved pollen grains in the peat, should be evidenced in the pollen spectra of all three bogs. A close correlation of results between the bogs further proves the validity of pollen analysis as an indication of forest succession.

The pollen in the lower eight levels of the three bogs revealed high Abies and Picea frequencies. A very rapid decline of the conifers followed by an increase in frequency of broad-leaved pollen marked another similarity. Salix, Ulmus, Quercus, Carya, Juglans, and the Betulaceæ appeared, in all cases, in the middle peat levels, although the frequencies varied, due probably to the local environment of the bogs. Quercus showed a similar trend in all bogs, appearing with the Abies-Picea decline and increasing gradually to the upper levels. Although represented by only a few pollen grains, Tsuga was found in all three bogs. Representation of hemlock in the Bacon's Swamp spectrum was limited to one pollen grain, found in the 12-foot level of boring III. Pinus was represented in all levels of boring III, but was most prominent in the levels above nine feet. A slight increase in Pinus frequency occurred in the 12-foot level, the point at which the Tsuga pollen grain was found. Rapid disintegration of Tsuga pollen when wet probably resulted in the virtual elimination of the genus from the pollen spectrum. Hemlock probably flourished during the period of pine prominence, much in the manner of the Michigan and Wisconsin subboreal forests, although this hypothesis cannot be proven from the fossil pollen analysis of Bacon's Swamp. This limited evidence is sufficient, however, to prove that Tsuga was represented in the forest succession of central Indiana.

The absence of pollen in the upper 12 levels of the Fox Prairie (17) bog prevented comparison of this portion of the spectrum with Bacon's Swamp. However, the Emporia bog (2) showed an interesting correlation with the upper ten levels of Bacon's Swamp. Quercus, having increased gradually from the time of appearance in the lower levels, decreased in frequency in the upper ten levels of both bogs. Carya, likewise, declined in this portion of the spectra. Juglans, Salix, Ulmus, and the Betula group dropped to the low-frequency classes. Acer and Fagus appeared about the 10-foot level and increased in frequency to the surface. Bacon's Swamp differed slightly from the Emporia bog in that these climax genera reached higher percentages at the surface, although the Acer-Fagus frequency curves were quite similar in the two bogs.

A comparison of the results from these central Indiana bogs with those of more distant bogs indicates that the forest stages after the glacier were quite general. Smith (21) reported results from the pollen analysis of Lake Cicott bog, in Cass county, which were similar to the findings in Bacon's Swamp. Abies and Picea controlled during deposition of the lower two levels of marl in Lake Cicott. The period of Abies-Picea dominance was much shorter, however, than in Bacon's Swamp, where the conifers controlled the spectrum throughout the lower 12 levels. This persistence of Abies and Picea in the lower levels of Bacon's Swamp seems to be characteristic in the southern bogs of Early Wisconsin glacial origin, for Barnett (2) and Prettyman (17) obtained similar results from bogs in Madison county and Hamilton county. The period of cool, moist climate which lasted for a time after glacial retreat, was evidently responsible for the Abies-Picea forest. This period must have continued much longer during retreat of the Early Wisconsin glacier than during the corresponding period following retreat of the Late Wisconsin substage. There is no vegetational evidence of a warm period between the two glacial advances which would have resulted in invasion of the conifers by a broad-leaved forest, followed by a return of conifers with the advance of the Late Wisconsin substage to within 60 miles of Bacon's Swamp. Malott (14) describes the retreat of the Early Wisconsin glacier as unsteady and marked by numerous recessions and readvances. Such a readvance resulted in the Late Wisconsin substage. A long period of glacial retreat and readvance in northern Indiana resulted in a prolonged period of cool, moist climate favorable to Abies-Picea control in the Bacon's Swamp region. However, the bogs formed by the Late Wisconsin substage show different results. Evidently, retreat of the substage was more rapid and consistent, resulting in a shorter period of climate favorable to the Abies-Picea forest.

A high representation of Pinus followed the rapid decrease of Abies and Picea in Lake Cicott.* This phase of succession is quite different from results obtained in central Indiana, where Pinus never occupied a prominent position in the pollen spectrum. Quercus and Carya appeared in Lake Cicott immediately following Pinus, and remained dominant to the surface level. The characteristic decrease of Quercus and Carya pollen in the surface levels of the southern bogs was not found in Lake Cicott. The absence of a period of Pinus prominence immediately following Abies-Picea retreat in the Bacon's Swamp region is probably due to a rapid warming up of the climate with considerable moisture still present. These climatic conditions favored the rapid increase to dominance of Quercus rather than Pinus and Carya. A warm, moist climate during this period is further evidenced by the increase of Salix, Populus, Larix, and the Betulaceæ. The warm, dry period favoring Pinus and Carya increases did not occur until the time represented by the 12-foot level in boring IV of Bacon's Swamp. Had the climate in central Indiana become dry as well as warm, following the cool, moist period, Pinus, and perhaps Carya, would have been prominent in the spectrum prior to the advances of the mesophytic broad-leaved forest, much in the manner of the Lake Cicott area. A further explanation for absence of the early period of Pinus prominence is the lack of sandy soil and hills in the Bacon's Swamp region. The flat, relatively low ground favored Quercus rather than Pinus as an early invader of the Abies-Picea forest.

Another difference in the upper levels of Lake Cicott bog was the low representation of Acer and Fagus pollen. Smith's results are quite similar to those obtained by Sears (19) in Bucyrus bog, who describes a period of Pinus prominence immediately following the disappearance of Abies and Picea from the spectrum, and preceding the rapid increase of Quercus and Carya. Houdek (13) found an Abies-Picea-Pinus-Quercus succession in Center Lake bog, near Gary, Indiana. Voss (22) also mentions Pinus as a dominant species following Abies and Picea in the successional stages of a northern Illinois bog.

Vegetation is an expression of climatic conditions. Gleason (12) states: "Migration of a species depends upon an environmental change in or beyond its range." The vast changes in the forest content of Indiana since glacial recession, as evidenced by the pollen spectrum of boring IV in Bacon's Swamp, indicate, therefore, corresponding changes in the climatic conditions of the region. With the retreat of the Early Wisconsin ice sheet, vegetational succession on the newly exposed land was initiated. The boreal forests which were driven south by the moving glacier are thought by Gleason (12) to have occupied a narrow strip between the ice sheet and the broad-leaved forest to the south. There is a question as to the existence of a tundra stage in the immediate vicinity of the melting ice during recession of the glacier. No microscopic evidence of a tundra was found in Bacon's Swamp, although such tundra plants could well have existed and disappeared before marl deposition in the lake began. Cooper (6) does not mention a tundra stage preceding the Abies-Picea forest in Glacier Bay, Alaska. Gleason (12), on the other hand, is of the opinion that a tundra stage did exist near the ice sheet on the newly exposed land formed during glacial recession. He believes also that rock barriers now supporting boreal relicts in mesophytic forest areas once harbored tundra relicts. If a tundra stage existed, the advancing Abies-Picea forest soon grew over it, for Cooper (6) describes the advance of the coniferous forest "on the heels of the retreating glaciers in Alaska." No doubt a similar condition existed in Indiana. Abies and Picea thrived in the cold soil resulting from glacial waters, but indications are that a tundra could hardly have existed under these conditions.

The persistence of the Abies-Picea forest through the period of deposition of 12 feet of marl and peat in Bacon's Swamp indicates a cool, moist climate. Gleason (12) states that, with glacial retreat, the narrow strip of coniferous forest broadened out to cover the newly exposed land. He believes, also, that the northward advance of the conifers was much more rapid than the southern retreat, resulting in time in an extensive coniferous forest. The presence of such a forest is evidence of a direct effect of the glacier on the climate of the adjacent regions. Perhaps the winds blowing across the ice sheet lowered the temperature of the region south of the glacier considerably, even though the general climate of the section might have been much like the present. Another factor contributing favorable conditions for the coniferous forest was the continued presence of icy waters flowing from the glacier. The width of the river beds in central Indiana are evidence of the size of these glacial streams. Numerous other streams, now extinct, no doubt also penetrated extensive areas south of the glacier. The general lowering of soil temperature and abundance of moisture and frost in the soil as a result of these icy waters, produced conditions favorable to an Abies-Picea forest and prevented invasion of the area by broad-leaved species for a considerable period of time.

The pollen spectrum of boring IV indicates a gradual decline of Abies and Picea frequencies during the period represented in the lower 12 levels of the bog. At the time of deposition of levels 19 and 20, an interesting change occurred in the forest. Abies dropped suddenly from a pollen frequency of 40 percent in the 21-foot level to 2.5 percent in the 19-foot level. This rapid decline of Abies was followed closely by a similar decrease in the Picea pollen frequency. The recession of the conifers was accompanied by a sudden increase in the frequency of broad-leaved species. Quercus, Salix, Juglans, Ulmus, and the Betulaceæ are shown to have invaded the Abies-Picea forest. This sudden change in the pollen spectrum suggests a climatic change in the region. The retreat of conifers and advance of the broad-leaved forest indicates a change from cool, moist conditions to a warmer, perhaps drier, climate. If the ice sheet and cold glacial waters in the soil were largely responsible for conditions favoring Abies and Picea, the recession of the glacier and resultant increase in temperature and drying out of the soil would mark the end of this coniferous forest. In the time required for deposition of 12 feet of marl and peat in Bacon's Swamp, the ice sheet could have melted to a point considerably north of the bog. Removal of the ice sheet and changes in river courses carrying the glacial waters might well have altered the climate in the Bacon's Swamp area. This warm, somewhat drier period was marked by a rapid increase of Quercus. Carya increased gradually but did not reach high frequeucies in the pollen spectrum. Betula also came into the spectrum in the low frequency classes. Quercus and Carya probably invaded the upland coniferous forest, while Juglans, Populus, Salix, and Ulmus came into the lowlands. Larix also shows a rapid pollen frequency increase at the 20-foot level, further indicating subboreal conditions. Local factors around the lake, such as formation of the Sphagnum mat, were no doubt also responsible for this Larix increase.

Another climatic change is indicated in the pollen frequencies of the 11-, 12-, and 13-foot levels of boring IV. Pinus and Carya show a sudden increase, while Betula, Salix, Populus, and Larix drop to the low frequency classes. The abundance of Pinus and Carya at this point in the spectrum indicates a period of increased dryness. The disappearance of Abies and Picea in these levels further snggests increased dryness and warmth.

Still another climatic change is evidenced during the formation of the upper ten levels. Acer pollen appeared in the spectrum in the 14-foot level and increased in frequency to 22 percent in the 1-foot level. Fagus pollen was first found in the 9-foot level and increased to 12 percent at the 1-foot level. This introduction of mesophytic climax species in the upper ten levels is an indication of a warm, moist climate. The increase in moisture at this time is further shown by the decline of Carya pollen from 27 percent in the 9-foot level to 8 percent at the 1-foot level. Acer and Fagus no doubt invaded the lowlands, while Quercus and Carya were prominent in the upland regions. Pine pollen remained in the spectrum to the 1-foot level, but showed no tendency to increase after its sudden drop in the 11-foot level. Juglans increased in the upper ten levels, while Ulmus showed a gradual decline. The mesophytic period is marked also by the absence of Betula, Alnus, and Corylus, and the scarcity of Larix pollen. Thuja appeared in the spectrum during this period. The Thuja frequencies are not representative, however, because of the decomposition of the pollen when wet (Sears, 18).

The absence of Fraxinus pollen from the spectrum during dominance of broad-leaved species is difficult to explain. It is a prominent secondary species in the modern forests of Indiana. Fraxinus was represented hy a few pollen grains in the 11-, 13-, and 14-foot levels, but was not found in the peat above that point.

In general, the period of increased moisture represented in levels 1-10 of the bog spectrum marked the increase of mesophytic genera. Acer and Fagus invaded the moist situations. Quercus probably remained dominant in the uplands and possibly invaded the lowlands, while Ulmus, Juglans, Salix, and Populus remained as secondary species in the lowlands. Carya, Pinus, and the Betulaceæ decreased, and Abies and Picea dropped out of the spectrum.

The migration of forests as shown in the pollen analysis of boring IV indicates a series of climatic changes. These periods, in chronological order are: first, a cool, moist climate dominated by Abies and Picea; second, a warmer and drier period, marked by a rapid decrease of the conifers and increase of the frequency of broad-leaved species dominated by Quercus. The third period, suggested by the rapid increase of Pinus and Carya and the decrease of Larix, Populus, and Salix, appears to have been even more dry. Evidence of such a period was found in the pollen content of the 11-, 12-, and 13-foot levels. A final period of increased moisture is marked by the rapid increase of Acer and Fagus pollen in the upper ten levels, and a corresponding decrease of Carya and Pinus pollen frequencies.

The climatic periods are similar to those described by Sears (20). However, the Bacon's Swamp results differed from Sears' results in the absence of a dry, cool period dominated by Pinus between the Abies-Picea forest and the invasion of the conifers by broad-leaved species. The migration of forests through central Indiana since Pleistocene times indicates ever-changing environmental conditions. This succession will probably never cease, since temperature and moisture conditions never become fixed in a specific region. Climatic changes result in migration of the vegetation. To use the word of Gleason (12), "Both advancing and retreating migrations are now in progress in the Middle West."

Comparison of the pollen frequency curves of borings III and IV revealed an interesting correlation between the two spectra. The reliability of the analysis of fossil pollen in peat as a means of determining past forest succession is further demonstrated in the results. Chance distribution of pollen grains on the active peat mats in the bog would naturally result in some variations in the pollen frequency curves of the two borings. However, considering that only a small amount of peat was mounted on a slide for examination and that the borings were made in opposite ends of the bog, the correlation of results shown in figure 2 is very striking.

The Abies-Picea frequencies in the first foot of marl deposited at the locations of the borings bear a marked similarity, showing a variation of only 2 percent in content of Picea pollen and 4 percent in Abies, indicating that marl deposition was instituted at about the same time in the region of both borings. The small difference might well be attributed to chance distribution of pollen on the mat. Further similarity is shown in tbe rate of increase of Picea and the gradual decline of Abies from that point in the spectrum. Both borings show also a rapid drop in frequency of Abies and Picea pollen following the period of dominance. While the decline is similar in the two borings, figure 2 shows that the rapid decrease occurred approximately four or five foot-levels later in boring IV than in III. The frequency curves which had compared closely in the lower seven levels of both borings became separated by about five foot-levels prior to the decline of the conifers in boring IV. Figure 2 shows that Abies and Picea pollen in boring IV failed to decline with the spectrum curves of boring III. High frequency of coniferous pollen was found in approximately five levels after the rapid drop in boring III. The period of Abies-Picea dominance is recorded in seven levels of boring III, while boring IV represented the same period in 12 levels of marl and peat. Furthermore, the correlation of frequencies in the lower seven levels of both borings and above the 12-foot level of boring IV definitely locates the five feet of deposition which contains the portion of the spectrum not represented in boring III. It is interesting to note that after this separation of the spectra curves between levels 20 and 25 in boring IV, deposition of peat occurred at about the same rate in both borings. The lines showing rapid recession of Abies and Picea are parallel, and the points of disappearance of the conifers from the spectrum are separated by approximately five foot-levels. Evidently, for some reason, during the period of deposition of one foot of marl in boring III just prior to the Abies-Picea decline, five feet of marl and peat were formed in boring IV, hence the separation of the frequency curves above that point in the bog by approximately five foot-levels. The reason for this more rapid deposition of peat and marl in boring IV during this period is uncertain. Perhaps a washing-in of deposited marl from other parts of the lake or an abundance of Chara or other marl-forming plants in the deep end may have been responsible.

Evidence of more rapid deposition of approximately five feet of marl and peat in boring IV while one foot was being formed in boring III is further shown in the separation of the frequency curves of Quercus, Carya, and Larix. Pinus showed such a fluctuation in percentages that comparison of frequencies in the two borings is difficult. However, the frequency curves of the other genera run consistently above the corresponding curves of boring III. These results of boring IV indicate also that after the period of more rapid peat and marl deposition in boring IV as compared with boring III, peat was formed in both ends of the bog at about the same rate.

Assuming that deposition did occur at the same rate in borings III and IV, the shallower region of the lake in which boring III was made would have filled sooner than the deeper end in the region of boring IV. Pollen grains are preserved only on active peat mats (Erdtman, 8). Therefore, the filling of the shallower end, resulting in the drying out

TABLE I

Pollen Percentages — Bacon's Swamp

Results of boring III are given on the upper line and boring IV on the lower for each foot-level, except from the 23rd through the 32nd foot-level the figures are for the fourth boring only.

Foot Level	Abies	Larix	Picea	Pinus	Thuja	Tsuga	Acer	Alnus	Betula	Corylus	Carya	Fagus	Fraxinus	Juglans	Populus	Quercus	Salix	Tilia	Ulmus
1	—	3	—	9	—	—	11	—	—	—	15	2	—	6	4	36	2	—	12
	—	—	—	6	—	—	22	—	—	—	8	12	—	5	3	31	4	2	7
2	—	6	—	9	—	—	9	—	—	—	14	4	—	5	5	37	8	—	3
	—	—	—	6	—	—	23	—	—	—	17	13	—	5	2	28	2	—	4
3	—	5	—	7	—	—	9	—	—	—	24	—	—	4	4	38	2	—	7
	—	1	—	10	2	—	23	—	—	—	10	13	—	4	4	28	—	—	2
4	—	6	—	5	—	—	6	2	1	3	21	—	—	8	2	37	2	—	7
	—	4	—	8	4	—	20	—	—	—	17	7	—	5	4	26	2	—	3
5	—	7	—	3	½	—	5	1½	1½	1	21½	—	—	10	2	36	2½	·	8½
	—	—	—	6	—	—	17	—	—	—	16	12	—	4	6	30	2	—	6
6	—	8	—	4½	—	—	3½	1	½	1	22	—	½	3	4½	36	2½	1½	12
	—	—	—	4	3	—	16	—	—	—	17	4	—	10	6	28	3	—	5
7	—	7	—	7	1	—	2	1½	3	3	19	—	—	3½	3½	32½	2	—	15
	—	—	—	4	3	—	15	—	—	1	17	2	—	7	—	36	3	1	12
8	—	4½	½	6½	—	—	2½	2	1½	2½	16½		—	3½	2½	35½	2	1	19
	—	1	—	6	—	—	12	1	—	—	20	1	—	5	—	34	4	—	16
9	5½	24	4	6½	1	—	1½	2	1½	2½	7	—	1	1½	3½	22½	3½	½	11
	—	1½	—	4	—	—	13½	½	½	—	27	—	—	½	½	38	2	1	10½
10	3	17½	5	3½	1	—	½	7	5½	2½	5½	—	—	2½	—	26	13	½	7
	—	1½	—	3	2½	—	10½	—	—	1½	25½	—	—	3	—	35½	½	—	14½
11	4½	20	5½	2	1	—	—	5	2½	2½	6½	—	—	1	—	24	17½	—	8
	—	2	1½	4½	3	—	7½	1	—	½	27½	—	1	—	—	34	1	—	17
12	7	14½	10½	3½	—	½	—	1	6½	4	8	—	—	—	—	19½	21	—	[illegible]
	4	15½	12½	23½	1½	—	3½	3	2½	3	6	—	—	½	½	17	3½	1½	7
13	10	21	27½	1½	—	—	—	—	3	2	8	—	—	—	—	13	9½	—	4½
	2½	19	9	8	1½	—	1	5½	2	2½	8	—	2	—	—	25	4	½	10½
14	32	15	40	2	—	—	—	—	2	½	—	—	—	½	—	8	—	—	—
	2½	21	4½	1	1½	—	2½	3½	4	2½	6½	—	2	—	½	29	5½	—	12½
15	38½	7	52½	1	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
	—	29½	3	½	—	—	—	3½	5½	5	4	—	—	½	—	26½	9½	—	11½
16	44	—	54	2	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
	½	32½	3	1	—	—	—	1½	7½	2	5	—	—	1	½	26	15	—	4
17	37	—	60	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	2½	19½	10	2	—	—	—	4	3½	2	4	—	—	2½	2½	22½	18	—	7
18	47	—	52	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	1	18½	11	½	—	—	—	7	10½	2½	2	—	—	4	½	19	16	1	6½
19	46	1	49	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	2½	14	22	5	—	—	—	3½	12½	1½	2½	—	—	2	—	18½	16	—	1
20	52	—	44	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26	10	48	3½	—	—	—	2½	3	½	½		—	—	—	1½	4½	—	—
21	54	—	42	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	40	3	51	½	—	—	—	½	½	—	2	—	—	½	—	1½	—	—	—
22	58	—	40	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	41	2	50	1	—	—	—	—	½	—	½	—	—	—	—	1	5	—	—
23	40½	3½	45	3	—	—	—	—	1	—	1	—	—	—	—	1½	3	—	—
24	46	—	50	2	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—
25	48	—	47	1	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—
26	47	—	50	1	—	—	—	—	—	—	—	—	·	—	—	—	1	—	—
27	45	—	54	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28	43	½	55	1½	—	—	—	—	—	—	—	—		—	—	—	—	—	—
29	50	1½	47	1½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30	56	½	43½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
31	60	½	39½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
32	62	—	38	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

of the Sphagnum mat, ended the pollen spectrum of boring III. The mat in the deeper end remained active longer and therefore continued the pollen spectrum beyond the end of boring III. This hypothesis is borne out, also, in the Acer-Fagus comparison. These genera, prominent in the upper levels of boring IV, are represented by much lower frequencies in boring III. Only the 1- and 2-foot levels of boring III contained Fagus pollen, while boring IV showed Fagus pollen in eight levels. The greatest frequency of Fagus in boring III was 4 percent, as compared with a frequency of 12 percent in the 1-foot level of boring IV. Acer pollen, although present in ten foot-levels in boring III reached only 11 percent in frequency at the 1-foot level, while it occurred in 14 levels in boring IV and reached a frequency of 22 percent. This comparison indicates that the pollen spectrum of boring III is not complete, the period of Acer-Fagus prominence shown in the upper levels of boring IV not being represented.

In general, the comparison shown in figure 2 illustrates several interesting facts. The close correlation of the pollen frequency cnrves shows the relatively even distribution of pollen over the surface of a bog. The similarity of results in the two borings further indicates the reliability of fossil pollen analysis as a method of determining past forest succession. Also, the absence of the upper portion of the spectrum of boring IV from the more shallow boring, suggests that the deepest part of a lake supports an active Sphagnum mat longest. Therefore, the most complete pollen spectrum should be obtained from analysis of a boring made in the deepest part of a bog.

SUMMARY

1. Bacon's Swamp is unique in its location near the southern border of Early Wisconsin glaciation.

2. Two borings made in opposite ends of the bog were analyzed for fossil pollen content of the marl and peat deposits.

3. Results showed a succession of forests from an early postglacial Abies-Picea control to the present Acer-Fagus-Quercus mesophytic climax.

4. Abies and Picea controlled during the period of deposition of the lower 12 levels of boring IV.

5. At the time of deposition of the 20-foot level, the conifers dropped suddenly and broad-leaved genera dominated by Quercus assumed control of the pollen spectrum.

6. Levels 11, 12, and 13 marked a period of rapid increase of Carya, Quercus, and Pinus, and a decrease of Ulmus, Salix, Populus, and the Betulaceæ.

7. The upper ten levels of boring IV marked the appearance of Acer and Fagus pollen in the spectrum, and an increase in frequency to a position of dominance. Carya declined rapidly, and Quercus showed a slight decrease.

8. Results were similar to those of other bogs in the region.

9. The forest succession suggests the following climatic periods: cool moist, moderate dry, warm with increased dryness, and warm moist.

10. A comparison of the spectra of borings III and IV shows a close correlation of results. Although the frequency curves paralleled in the lower seven levels of both borings, they were separated consistently by five foot-layers above the 12-foot level of boring IV.

11. The period of Acer-Fagus prominence shown in the upper ten levels of boring IV is absent in boring III, indicating that the pollen spectrum of boring III is not complete because of earlier filling-in of the shallower part of the lake.

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LITERATURE CITED

1. BARKLEY, F. A. The statistical theory of pollen analysis. Ecology 15:283-289. 1934.
2. BARNETT, JEAN. Pollen study of Cranberry pond, near Emporia, Madison county, Indiana. Butler Univ. Bot. Stud. 4:55-64. 1937.
3. BARRETT, EDW. Glaciation and its relation to the soils of Indiana. Thirty-sixth Report Dept. Geology and Natural Resources Indiana. 1911.
4. CAIN, STANLEY A. Plant succession and ecological history of a central Indiana swamp. Bot. Gaz. 86:384-401. 1928.
5. COLLETT, RYLAND T. Report of a geological and topographical survey of Marion county, Indiana. Twelfth Report of State Geologist. 1882.
6. COOPER, W. S. A third expedition to Glacier bay, Alaska. Ecology 12:61-95. 1931.
7. DOUGLAS, B. W. The uses of peat as fuel. Indiana Acad. Sci. Proc. 15:41-47. 1905.
8. ERDTMAN, G. Boreal forests and the theory of pollen statistics. Jour. Ecology 19:158-163. 1931.
9. FRIESNER, RAY C., and J. E. POTZGER. Studies in forest ecology. I. Factors concerned in hemlock reproduction in Indiana. II. The ecological status of *Tsuga canadensis* in Indiana. Butler Univ. Bot. Stud. 2:133-149. 1932.
10. —— Climax conditions and the ecological status of *Pinus strobus, Taxus canadensis,* and *Tsuga canadensis* in the Pine Hills region of Indiana. Butler Univ. Bot. Stud. 3:65-83. 1934.
11. GEISLER, FLORENCE. A new method of separation of fossil pollen from peat. Butler Univ. Bot. Stud. 3:141-146. 1935.
12. GLEASON, H. A. The vegetational history of the middle west. Ann. Assoc. Am. Geog. 12:39-85. 1923.
13. HOUDEK, P. K. Pollen statistics from two Indiana bogs. Indiana Acad. Sci. Proc. 42:3-7. (1932) 1933.
14. MALOTT, C. A. The physiography of Indiana. Handbook of Indiana geology. Part II. 66-256. 1922.
15. POTZGER, J. E. A notable case of bog formation. Amer. Mid. Nat. 15:567-580. 1934.
16. —— Acidity of dunes and bogs. Indiana Acad. Sci. Proc. 47. (1937) 1938.
17. PRETTYMAN, ROBERT. Fossil pollen analysis of Fox Prairie bog, Hamilton county, Indiana. Butler Univ. Bot. Stud. 4:33-42. 1937.
18. SEARS, PAUL B. Common fossil pollen of the Erie basin. Bot. Gaz. 87:95-106. 1930.
19. —— Postglacial climate in eastern North America. Ecology 13:1-6. 1932.
20. —— Climatic changes as a factor in forest succession. Jour. For. 31:934-942. 1933.
21. SMITH, WILLIAM. Pollen spectrum of Lake Cicott bog, Cass county, Indiana. Butler Univ. Bot. Stud. 4:43-54. 1937.
22. VOSS, J. Pleistocene forests of central Illinois. Bot. Gaz. 94:808-814. 1933.
23. WODEHOUSE, R. P. Pollen grains. McGraw-Hill. 1935.